History of the flextensional electroacoustic transducer[a)]

Kenneth D. Rolt[b)]
Raytheon Company, Submarine Signal Division, Portsmouth, Rhode Island 02871-1087

(Received 30 January 1989; accepted for publication 26 October 1989)

The flextensional electroacoustic transducer is resurging as a candidate for high-power, low-frequency active sonar. It has experienced steady investigation and development since the late 1950s and is popular enough now so that it is even advertised in naval and ocean-related publications. Despite this popularity, the history of its invention and development has remained cloudy. The invention is usually credited to William J. Toulis during the late 1950s. However, at least two flextensional designs were invented, developed, and constructed during 1929–1936 by a pioneer in underwater acoustics, Harvey C. Hayes, at the U. S. Naval Research Laboratories in Washington, DC. These flextensionals were intended as aeroacoustic foghorn sources. The Hayes flextensionals then vanished from development during the mid-1930s, and the concept was not revisited (in the U.S.) until the mid-to-late 1950s by Toulis and Frank R. Abbott at the U. S. Naval Electronics Laboratory, San Diego, CA. This paper will review the history of the flextensional transducer beginning with Hayes' work, review the classes of flextensional transducers, and discuss modern flextensional transducers.

PACS numbers: 43.88.Ar, 43.10.Ln, 43.28.Tc, 43.30.Yj

INTRODUCTION

It has been widely considered in both industry and in the literature[1–3] that William J. Toulis invented the flextensional electroacoustic transducer, in part due to his 1966 patents[4,5] and because he investigated the device in the middle-to-late 1950s. In fact, a flextensional transducer was constructed and tested in May 1929 at the Anacostia Naval Research Laboratories[6] (NRL), Washington, DC, based on the invention of Harvey C. Hayes, the Director of the NRL Sound Division. This transducer is shown in Fig. 1. It predates both Toulis' work and flextensional patents by over 25 years. Furthermore, a 1936 patent by Hayes[7] titled "Sound Generating and Directing Apparatus," which describes the theory and design of (the now-called) flextensional transducers, is listed in Toulis' patents as the oldest reference cited. Although Hayes' patent was listed in Toulis', it has been overlooked by most readers. This paper will review the history of the flextensional transducer in four parts: The first, Sec. I, will show the flextensional work of Hayes during 1929–1936 and show how his work on the flextensional was forgotten; Sec. II will show the rebirth of the flextensional transducer, largely due to the work of Toulis; Sec. III discusses the nomenclature of the flextensional, i.e., where the name came from, and how the different classes of flextensionals are organized; Sec. IV will review some of the modern flextensional designs, materials, and design innovations. The paper is then concluded in Sec. V and is followed by extensive annotated references.

I. HAYES' PATENT AND FLEXTENSIONAL WORK

The text of Hayes' 1936 patent is revealing, and I urge the interested reader to obtain a copy. Even more so, however, are the illustrations of the patent that are shown here in Fig. 2. These illustrations show that Hayes understood and convincingly explained how a flextensional transducer worked. Hayes' Fig. 1 shows a schematic electromechanical circuit having two pistons driven by a length-vibrating magnetostriction drive rod. Hayes shows the alternating-current drive source and the direct-current bias to prevent frequency doubling. Figure 2 shows side and hidden views of the drive rods and coaxial coils that are contained within the oval shell structure. This is also shown in Fig. 3 from an end view.

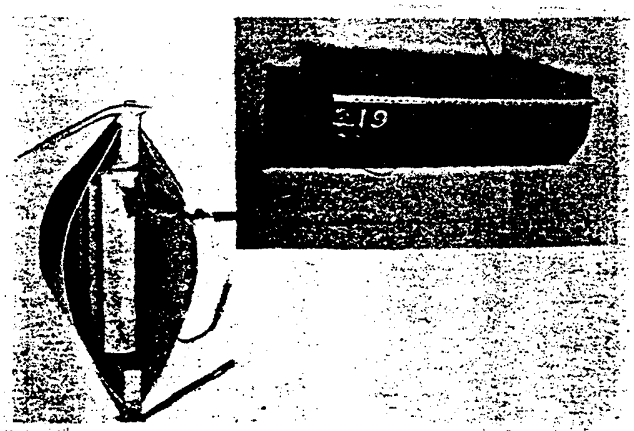

FIG. 1. Foghorn magnetostriction-driven oval shell flextensional transducer built at the Naval Research Laboratories, Washington, DC in May 1929 (from Ref. 6).

a) Portions of this paper were presented at the 117th Meeting of the Acoustical Society of America [J. Acoust. Soc. Am. Suppl. 1 85, S90 (1989)].
b) Present address: Department of Ocean Engineering, MIT, Bldg. 5-007, 77 Massachusetts Avenue, Cambridge, MA 02139.

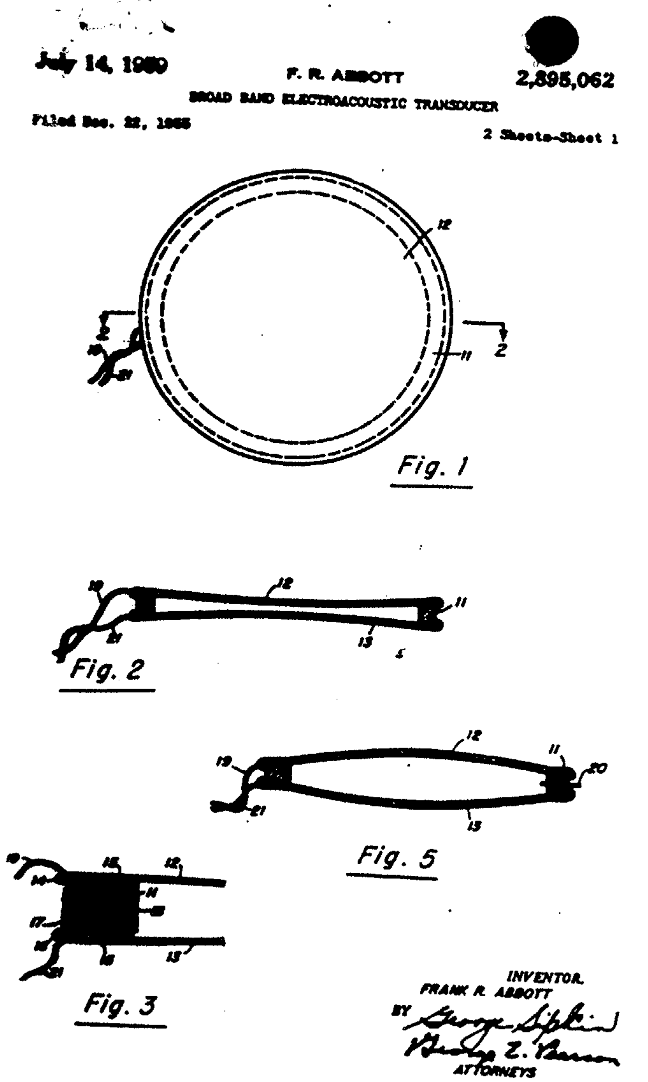

FIG. 5. Illustration sheet from F. R. Abbott's 1959 patent (Ref. 17) of a ceramic-driven flextensional transducer.

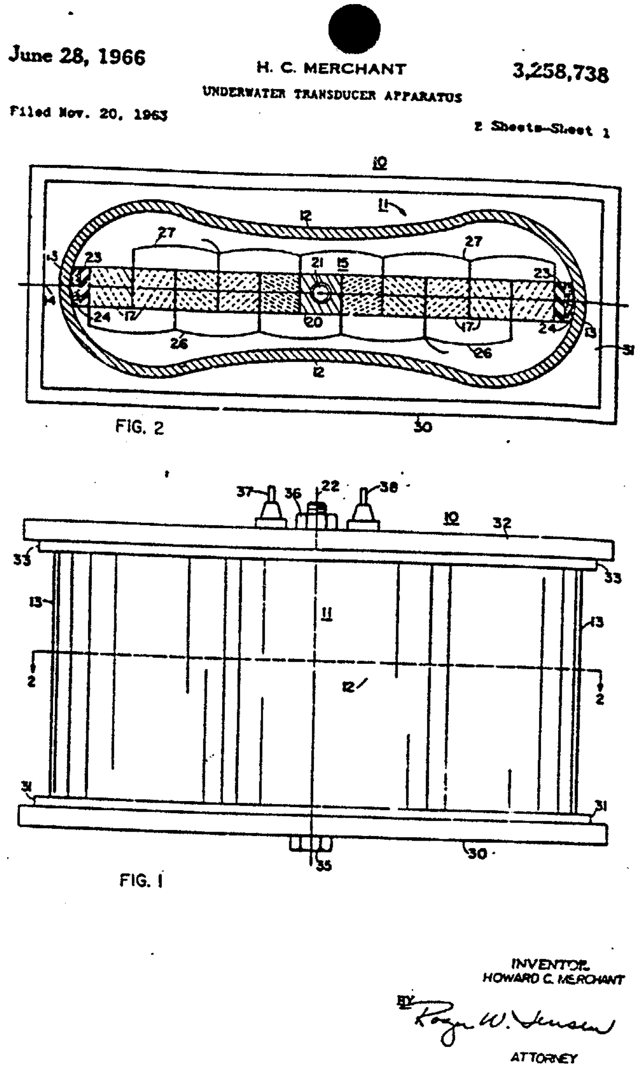

FIG. 6. Sketch from H. C. Merchant's 1966 patent (Ref. 18) of a ceramic-driven, concave shell flextensional transducer.

accordingly, shown to representatives of the Lighthouse Service with the result that this service agreed to finance the development to a limited extent..."

"...The first design carried two convex oscillating plates, the cross-section of which resembled the double bow mentioned. The second carried four concave oscillating plates. The two plate device lacked considerably of giving uniform intensity about the azimuth. The four plate device largely overcame this defect but introduced a tendency for the plates to drift out of phase to one another. The radiating area of the two plate device was 14 sq. ft. and of the four plate device 28 sq. ft. A study of the behavior of the four sided device led to the conclusion that the phase drift could be avoided by going to a six-sided device with the several magnetostriction driving members all attaching to a common central member. A section one foot high was constructed and proved satisfactory..."

"Meantime we have, on another problem, learned how to vigorously oscillate tubes in a radial direction so that all parts operate vigorously in phase. The acoustical efficiency of these devices is fully as high as those using the "bow" type of drive. The construction is simpler and cost considerably less. The ruggedness of these cylindri-

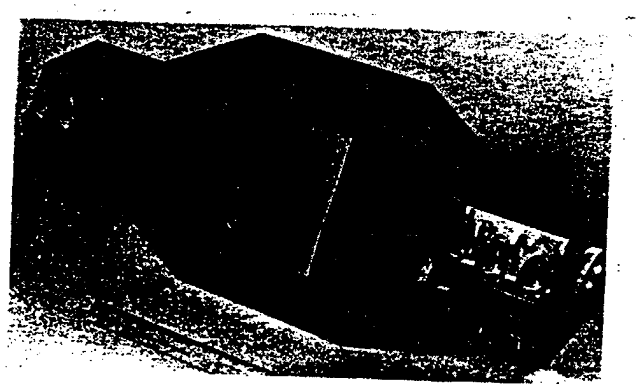

FIG. 7. Example of a Class I flextensional transducer (photo courtesy of L. H. Royster).